

Dr. Lundquist

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1090

ON THE PROBLEM OF STRESS CORROSION

By L. Graf

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The object of the present work is first to investigate accurately the processes during stress corrosion, in particular, for light metal alloys and, as the first part of the investigation, to determine its laws; and secondly to explain its causes for various alloys and thereby find means for its partial or complete elimination and thus make possible the production of light metal alloys free from any stress corrosion. In the present paper some of the results of the investigation are given and the fundamental problems of stress corrosion discussed.

SUMMARY

1. The intensity of the elastic stress in polished specimens is determined roentgenographically for various hydro-magnesium alloys. It is found that the elastic stress often approaches the tensile stress of the material but in the course of time is very greatly reduced. The specimens for determining the stress corrosion sensitivity of a material must therefore be used with a certain amount of caution.

2. The crack formation and development in stress corrosion is investigated for AZM sheet of many-crystal and single-crystal layers, respectively. Particularly to be noted is the extremely sharp formation of the stress corrosion cracks in single crystals. No preference for any special crystallographic orientations could be established, the crack development being always at right angles to the direction of the tension.

3. The effect of the elastic stress and plastic deformation on the stress corrosion for AZM sheet is accurately investigated, and it is found that the stress corrosion sets in with the start of the first plastic deformation. There is

¹ "Zum Problem der Spannungskorrosion." Luftwissen, vol. 7, no. 5, 1940, pp. 160-169.

thus found the existence of a limiting stress below which no stress corrosion occurs. By predeformation the limiting stress may be displaced more and more toward lower stresses and practically be made to vanish. Plastic deformation without elastic stress does not increase the corrosion sensitivity of the material. The absence of stress corrosion for the cast alloys AZF and AZG is to be ascribed to the special position of the limiting stress above the plastic limit of these alloys.

4. As a cause of the stress corrosion, sensitivity or the intercrystalline corrosion in the majority of alloys may be considered the high dispersiveness of the precipitated phase with at least partial microscopically inhomogeneous precipitation. A brief discussion of the most recent state of knowledge of the precipitation processes is therefore given.

DETERMINATION OF THE STRESS CORROSION SENSITIVITY

BY MEANS OF POLISHED SPECIMEN TESTING

The microscopic examination method is a practical test method for the rapid and simple determination of whether and to what extent a substance tends to stress corrosion. (See reference 1.) The great advantage of simplicity of the procedure, which may be here assumed as familiar, is offset by certain disadvantages: namely,

1. The inaccurate knowledge of the magnitude of the elastic stress
2. The gradual reduction of the elastic stress

The magnitude of the elastic stress generally affects the behavior toward stress corrosion only quantitatively - that is, the failure of the specimen occurs earlier with increasing stress. In the case of certain alloys there exists, however, a so-called "limiting stress" (see fig. 14) below which no stress corrosion occurs. In these cases, therefore, the stress should not go below a certain minimum value. This requirement is initially always satisfied, as will be shown, for all test specimens. However, the gradual reduction of the stress may give an increased life of the specimen and even deceive as to the freedom from corrosion stress if the stress is below the limiting stress.

The principal cause of the decrease in stress is the creep of the specimen, but there is also a decrease in load due to the slight crack formation during the corrosion. It is found, in fact, in practice that specimens which do not crack in the first few days often develop an abnormally long life although the material is not much better than in the case of specimens that have cracked earlier. The specimens often do not fail at all; whereas accurate investigation showed numerous fine crack formations.

For the above reason it appeared to be of interest to know accurately the magnitude of the elastic stress of test specimens and its variation with time. X-ray stress measurements in 1939 at the Technical High School at Stuttgart were therefore carried out by O. Schaaber on specimens of various "hydronalium" alloys. The measurements were always made in the center of the specimen; the results are given in table 1.

TABLE 1.- THE MAXIMUM STRESSES AND THEIR VARIATION
WITH TIME IN "HYDRONALIUM" SPECIMENS
ACCORDING TO X-RAY STRESS MEASUREMENTS OF O. SCHAABER

Alloy	Days after bending	Longitudinal stress (kg/mm ²)	Transverse stress (kg/mm ²)	Initial tensile strength (kg/mm ²)
Hy 7 HH	2	26	25	35 to 38
	6	13	19	
	14	10	19	
Hy 7 W	1	20	16	31 to 36
	7	17	13	
Hy 16 HH	1	25	--	40
	13	23	25	
Hy 16 W	1	19	--	
	2	--	18	
Hy 9 HH	2	34	23	39 to 42
	15	19	21	
Hy 9 W	1	28	--	36 to 40
	2	26	15	
	8	25	17	
	14	26	17	
Hy 18 HH	1	34	--	42
	2	35	26	
	21	25	11	

As may be expected, the initial stresses are, in general, very high and attain the tensile strength. It is to be observed that the measurements were taken only 1 or 2 days after the bending of the specimen. A surprising fact is the great change in the elastic stresses, which in about 14 days often amounts to more than 50 percent of the initial stress. Another fact to be observed is the high transverse stresses which often attain the magnitude of the longitudinal stresses and, in general, vary less with time than the latter. The high transverse stresses were observed, for example, in a test of Althof (reference 1) from the fact that unstressed specimens received longitudinal cracks during the corrosion; whereas in the case of stressed specimens only transverse cracks, in general, appeared. On the basis of this result a certain caution is in any case to be used in evaluating alloys with respect to their stress-corrosion sensitivity with the aid of polished specimens, in particular, if the testing time is long, whether on account of the small stress-corrosion sensitivity of the material or the use of a weak corroding medium. In these cases the test specimen always leads to a too favorable result.

CRACK FORMATION IN THE STRESS CORROSION OF Mg ALLOYS

Whereas in the case of the alloys on an aluminum basis (for example, "hydronalium") the stress corrosion cracks are always intercrystalline in the case of alloys on a magnesium basis, the crack development is not as yet entirely clear. It may develop in this case both intercrystalline as well as intracrystalline (fig. 7). In what follows, a brief view will be given with the aid of several pictures of the processes during the crack formation in Mg alloys and an attempt will be made to explain their possible causes in the texture. The investigations are limited so far to the alloy AZM with about 6 percent Al, 1 percent Zn, 0.3 percent Mn, and the remainder Mg.

The object of the test was to investigate the formation and development of the stress corrosion cracks through direct observation under the microscope of the elastically stressed specimen covered with a corroding medium. This was successfully done by the use of a small stress frame in which a spring-loaded specimen could be observed under the microscope. Figure 1 shows a stress corrosion crack in AZM in the initial state of delivery taken during corrosion by the corroding

medium. There may be observed the gas bubbles rising from the depth of the crack to the surface. The crack runs almost perpendicular to the direction of the tension with only slight deviations here and there; in addition, further smaller cracks occur nearby. The crack development in the structure as shown in figure 2 is rather irregular, passing sometimes through the grains and sometimes along the grain boundaries and slip planes. The growth of the crack - that is, its further penetration - could be directly observed through the microscope. In about 50 minutes it penetrated the entire field of view of about 0.5-millimeter diameter so that a linear rate of increase of about 1/100 millimeter per minute was obtained. Its development occurred generally without any formation of gases and so irregularly that it could not be predicted which path would be taken in the next moment. Often it develops beneath the surface and then suddenly appears at the surface at a removed point.

An attempt was made to determine the starting point and cause of the crack in the texture. For this purpose homogenized rough crystalline specimens were used in order to have better defined initial conditions. It was first tested whether the fine cracks which occur in the plastic deformation of the material in unfavorably oriented crystallites are the starting points for the stress corrosion cracks. Figure 3 shows such a position arising through plastic deformation with many fine cracks in the center crystal. Figure 3 with larger magnification gives a somewhat enlarged view of the same region, lying approximately in the center of the picture as figure 4. The specimen, under elastic stress, was corroded through continued wetting with distilled water for about 3 hours (fig. 5). The originally observed cracks are now more clearly defined but, as accurate measurement showed, did not become any larger. At another place, however, a considerable crack had developed in the same time which may be seen in figure 6 more clearly than the first observed cracks. A subsequent determination of the start of this crack was, however, not possible. It follows, however, from this that the cracks arising from plastic deformations are not the primary cause for the origin of the stress corrosion cracks. Another as yet unknown factor must enter which accelerates the crack development to such extent.

There was also investigated whether the slip planes, to which fundamental significance had been ascribed for the stress corrosion of Mg alloys, take part in the development of the cracks. (See reference 2.) Figure 7 shows the crack development near the failure position of a homogenized

rough crystalline specimen. The crack passes partly along the grain boundaries and partly through the grain without utilizing the slip planes. Similar cases are very frequently observed (fig. 8). Although now and then stress corrosion cracks are observed in the slip planes it must be concluded that the latter are likewise not the primary cause for the origin of stress corrosion cracks.

Since the grain boundaries in a multicrystal material may affect the cracks in unfavorably oriented grains, and in particular the superposition of the crystallites may affect the place of occurrence of the crack and the crack development in a purely accidental manner, tests with single crystals promised to give a much clearer insight into these processes. Stress corrosion tests were therefore conducted on single-crystal specimens which were produced from 0.5-millimeter thick AZM sheet by recrystallization. The crystallographic orientation of the specimens is such that the hexagonal base was almost at right angles to the plane of the sheet and almost parallel to the longitudinal axis or direction of the tension. The required load for a small plastic deformation amounted to only about 4 kilograms per square millimeter. The corrosion was again obtained with distilled water directly under the microscope. The results thus far obtained are limited to the shape and development of the cracks but already some interesting information is obtained. As shown in figure 9, the stress corrosion cracks are here unusually sharp, as though ruled, and are exactly at right angles to the direction of the tension. This shows up even more clearly after light polishing of the corroded surface (fig. 10). To be noted also is the fact that over their entire original length the cracks reach below the surface and not only at individual points. The orientation of the cracks at right angles to the direction of the tensile stress holds even better beneath the surface than on the surface. Somewhat bent cracks divide beneath the surface into several parallel cracks, as figure 11 for the case of a strongly polished specimen clearly shows. The cracks run apparently without any preference or any crystallographic direction of the specimen, as is also shown by the fact that small inclusions of differently oriented crystals in no way disturbed the crack development or its direction at right angles to the tension.

CONDITIONS FOR THE OCCURRENCE OF CRACK CORROSION

For the occurrence of crack corrosion, according to the

investigations so far conducted, the following conditions must be satisfied:

1. The action of a corroding agent (gas or liquid)
2. Elastic stresses in the material (internal or external)
3. Plastic deformation of the material
4. Basic physical condition of the material

1. With regard to the action of the corroding agent, the following observation may be made which concerns the difference in the corrosion mechanism between the alloys on an aluminum basis on the one hand and those on a magnesium basis on the other. Whereas, in the case of aluminum alloys, the stress corrosion, as is known, is considerably accelerated by exposure to the air; the magnesium alloys corrode only if the required moisture is present, for which purpose distilled water is sufficient. From this, perhaps, certain conclusions can be drawn with regard to the composition of the strongly corroding components, in particular for the alloys on a magnesium basis. In agreement with this result is the observation that for AZM the curve of the life of the specimen as a function of the elastic stress does not vary if in one case the specimens remained continuously immersed in water and in another case exposed to air. The curves have only been displaced parallel in correspondence with the retarded attack of the corrosion in the free atmosphere (fig. 18).

2 and 3. Whereas there is no doubt that the first and fourth condition must always be satisfied for the occurrence of stress corrosion, there is still considerable doubt with regard to the action of the two conditions, 2 and 3. It is necessary that both be absolutely satisfied simultaneously or is only one of the two required, and if so, which? It is still quite uncertain whether, for example, the internal stresses during cold formation or the deformations themselves are essential. The latter, for example, accelerate the precipitations and thus give rise to corrosion-sensitive states. An important part of the solution of the complete problem of stress corrosion was, therefore, to determine accurately the effects of elastic stress and plastic deformation and separate them as far as possible. This object was attained through the simultaneous measurement of:

- (a) The stress acting during the corrosion attack
- (b) The magnitude of the elastic and plastic deformation of the material for each stress for various pre-treatment of the specimens

To carry out these tests the apparatus shown in figure 13 was used. It was possible to test simultaneously eight specimens up to 115-millimeter length for each desired stress, which was produced by springs. The lower eight stress bolts of the apparatus have a displaceable spherical hinge to avoid bending of the specimens or for exact adjustment of the latter in the direction of the tension. The upper eight bolts ran in a guide and carried the stress springs. Spherical hinges and springs were enclosed in unscrewable protective caps at both ends of the apparatus in order to avoid contact with the corroding medium. All parts were strongly chromed and, in addition, the specimens were insulated from the apparatus by mica layers. The apparatus could be used in its horizontal position about its center axis as an immersion apparatus; in which case it was immersed about halfway into the corroding medium. As mentioned before, in the case of Mg alloys the air does not favor corrosion but retards it. In this case, therefore, the apparatus was continuously immersed vertically in the corroding medium (water) up to complete covering of the specimens. The life of the specimens was recorded automatically by a simple electrical counter device.

The results of the measurements are given in the following figures: Figure 14 shows the behavior of AZM in the initial delivery state. The ordinate gives the life of the specimen in hours and the abscissa the stress in kilograms per square millimeter. A surprising fact is the very strong dependence of the life of the specimen on the load, although this is known qualitatively from other investigations. (See references 2, 3, and 4.) It is to be observed that the plotted points of the curves are individual measuring points and not mean values. The scatter, contrary to expectations, is thus very small and the curve may with good approximation be represented by a hyperbola of the second order; that is,

$$L \approx 1/p^2$$

where L is the life in hours and p the load in kilograms per square millimeter.

A fundamentally new result, however, is the determination of a direct "limiting stress" below which no stress corrosion or any stronger corrosion is to be observed but on exceeding which very rapid and strong stress corrosion sets in. This limiting stress is approximately at 8 kilograms per square millimeter and thus lies below the plastic limit $\sigma_{0.2}$ of about 20 kilograms per square millimeter and the elastic limit $\sigma_{0.02}$ of about 12 kilograms per square millimeter. As shown by an accurate measurement of the mechanical properties of the sheet specimens, this limiting stress coincides with sufficient accuracy with the start of plastic deformation of the material. This is very clearly seen in figure 15, giving the life L as a function of the stress and also the reciprocal curve $1/L$ which may be taken as a measure of the tendency to stress corrosion. The curve D is given by the ratio of the plastic to the elastic deformation and is a direct measure for the plastic deformation as a function of the stress. It may be seen that the occurrence of the stress corrosion coincides very accurately with the start of the plastic deformation, plastic deformations of less than 0.01 percent being considered at which the stress corrosion already becomes observable. This is the first reliably determined case in which the occurrence of stress corrosion could be directly associated with plastic deformation of the material.

There still remains to be explained the effect of the elastic stress. Does the latter act only indirectly through the plastic deformation or does it of itself have a special effect? Are any elastic stresses at all required after plastic deformation? To answer these questions, a large series of undeformed specimens and of specimens plastically deformed about 8 percent in the testing apparatus were corroded in the unloaded state. The corrosion period extended over 300 hours. At definite time intervals the undeformed and deformed specimens were taken and their strength and expansion after failure determined. Not the slightest differences in the corrosion behavior were observed between the variously pretreated specimens. All of them were equally corrosion-resistant in the unstressed state. (See fig. 16.)

As a control test predeformed specimens were corroded under different elastic stresses. The predeformation was chosen of various amounts: namely, 0.2 percent, 2 percent, 8 percent residual expansion, and 8 percent rolled in order to determine the magnitude of their effect. The test results are given in figure 17 and show that with increasing plastic predeformation the limiting stress shifts constantly toward

smaller values and finally almost entirely vanishes at large predeformations. This means that once the stress corrosion sensitivity is produced by a deformation, the corrosion rate or the life of the specimen depends only on the value of the elastic stress and very slight stresses are then sufficient to produce a strong stress corrosion. This result is of practical importance; for not only the internal stresses in a cold-formed structure but also the magnitude of the plastic residual deformation is a deciding factor for the stress corrosion sensitivity of the material.

Of interest, also, is the behavior of different Mg alloys, and two cast alloys will therefore be discussed briefly: namely, the behavior of the alloys AZF with about 4 percent Al, 3 percent Zn, and 0.3 percent Mn; and AZG with about 6 percent Al, 3 percent Zn, and 0.3 percent Mn. No measurements are as yet available on these but from several numerical results from a paper by G. Siebel (reference 2) there can be obtained the fundamental behavior of the life of the specimen as a function of the stress, as shown in figure 18. It is to be noted here that both cast alloys, which in practice are assumed as completely free from stress corrosion, nevertheless show the same stress corrosion curve as AZM, although with considerably less absolute sensitivity (life measured in days and not in hours). This, however, does not explain the fundamental difference in the practical behavior of these cast alloys as compared with the rolled AZM alloys. The cause is rather the following: The limiting stress ($\sigma_K = 11 \text{ kg/mm}^2$) up to which the cast alloys remain free from stress corrosion here lies above the plastic limit ($\sigma_{0.2} = 9 \text{ kg/mm}^2$) of these alloys. In this case, therefore, much greater plastic deformations are required to produce the tendency to stress corrosion than is required in the case of AZM. Since the designer does not exceed the plastic limit of the material, the tendency to stress corrosion in the case of cast alloys is never produced and the latter remain free from corrosion in spite of possibly existing elastic stresses.

4. In conclusion, a somewhat more detailed discussion will be given of the most important condition for the occurrence of stress corrosion, namely, the basic physical condition of the material. As is known, unalloyed metals like Al or Mg show no corrosion under any conditions, nor alloys for which the alloyed component does not exceed or only slightly exceeds the solubility limit of the latter. With increasing saturation, however, the stress corrosion sensitivity increases to a very large extent, as may be seen from the curves

of figure 19. The values for these curves were taken from a paper by Althof. (See reference 1.) The first, almost generally valid, condition for the occurrence of stress corrosion sensitivity is, therefore, that the material must be supersaturated at room temperature.

Two main groups of substances may be distinguished: namely,

- a) Alloys for which the stress corrosion sensitivity may be affected and possibly eliminated by heat treatment
- b) Alloys which are sensitive to stress corrosion independent of any heat treatment

The first group includes the greater number of the known alloys sensitive to stress corrosion, in particular the alloys based on aluminum. As chief representative of the second group there are the alloys based on magnesium, in particular the rolled alloy AZM. In the case of this group it is as yet not entirely clear which factor gives rise to stress corrosion sensitivity so that it has not as yet been possible to influence or eliminate it.

On the other hand, the cause of the stress corrosion sensitivity in the case of the alloys of the first group is known. It is known that it is the precipitations at the grain boundaries which under certain conditions produce a tendency to intercrystalline corrosion and, in the presence of elastic stresses, also to stress corrosion. Between intercrystalline corrosion and stress corrosion for these alloys there is, as is known, only a quantitative difference, the elastic stresses considerably accelerating the corrosion. (See reference 5.) Since it is a question of precipitation processes, the stress corrosion sensitivity can be greatly influenced by heat treatment. An unfavorable heat treatment raises the sensitivity extraordinarily, the increase being greater the higher the supersaturation at room temperature. (See fig. 19.) The homogeneous supersaturated state is completely insensitive to stress corrosion.

The cause of the stress corrosion sensitivity lies, as is known, not in the heterogeneous condition of the texture itself but in the highly dispersive form of the precipitated phase, such as may arise if the precipitation occurs at low temperature. A direct confirmation of this is furnished by

the comparison of the X-ray lattice constant measurements of Glocker and Giesen on duralumin with the corrosion investigations of Mann (fig. 20). The increased corrosion starts simultaneously with the first precipitations indicated by the X-ray measurements. A knowledge of the origin of the highly dispersive precipitations is, therefore, of greatest practical importance for hindering the occurrence of intercrystalline corrosion. Therefore, in view of this, there is presented a brief review as regards the most recent state of knowledge of the precipitation processes. (See reference 6.)

In investigating the precipitation processes, the first question is, where does the precipitation start? The answer is that it starts, at any temperature and under any other conditions, always at the boundaries of the "mosaic" crystals. The mosaic crystals are the building stones of the visible real crystals in the same way as the molecules are the building stones of the organic or inorganic substances, and are of the order of magnitude 10^{-4} mm - that is, below the resolving power of the microscope. A real crystal of 1 mm^3 therefore contains about 10^{12} mosaic crystals the boundary surfaces of which for atomic orders of magnitude form correct "grain boundaries" at which the atoms may be precipitated. When it is considered what tremendous precipitation surface within a real crystal is available for the precipitated atoms, it becomes understandable why the precipitations are so highly dispersive and not demonstrable microscopically. It has, nevertheless, been fully confirmed experimentally that the atoms are actually precipitated from the base lattice at the mosaic boundaries because the lattice constant in this state of the precipitation is changed according to X-ray investigations (fig. 20). This state may, however, also be macroscopically observable in a more intensified chemical activity or in a smaller resistance to corrosion, polished specimens being etched mat or black.

If the precipitation occurs simultaneously for all mosaic crystals of a real crystal (fig. 21), this is denoted as a "microscopically homogeneous precipitation." In this case the real crystal is uniformly coarsened and, in general, an increased corrosion attack on the entire crystal may be expected. This is a form of corrosion that practically can readily be taken into account, for it leads to a uniform wearing away of the material and not to locally restricted and, therefore, more dangerous corrosion.

Frequently, however, the actual grain boundary which plays no primary part in the precipitation has a strongly

accelerating effect on the precipitation of its neighboring zones because of special stress conditions at the grain boundaries. This leads to the result that the precipitation along the true grain boundaries first occurs at the mosaic boundaries in more or less wide zone, while in the interior of the crystal the precipitation has not yet begun (figs. 22 to 24). This precipitation process is denoted as "microscopically inhomogeneous." In this case, a very dangerous condition sets in, since the unaffected regions in the interior of the homogeneous crystallite adjoin the affected regions at the true grain boundaries. A strong tendency thus arises toward intercrystalline corrosion. This tendency, however, exists only as long as the atoms are in the highly dispersed state at the mosaic boundaries. This condition is attained only at low initial temperatures at which the mobility of the precipitated atoms is so slight that they do not again combine to form new crystals after the precipitation. At higher temperatures, and therefore higher mobility, the precipitated atoms combine immediately to form larger crystals, so that the high chemical activity of these zones and therefore the danger of intercrystalline corrosion is again removed or at least greatly reduced.

Figures 22 to 24 show an example of a microscopically inhomogeneous precipitation for an Ni-Be alloy with about 6 percent Be in various states. There is clearly observable the formation of black zones along the grain boundaries, which become increasingly wide; while at the center of the crystallite there is hardly any precipitation. In the case of many alloys, however, the microscopically homogeneous and the microscopically inhomogeneous precipitations are superposed. Figure 25, for a supersaturated Cu-Ag alloy, shows that also for the precipitation of noble metals intercrystalline corrosion may occur and the black zones form along the grain boundaries. This example is also of importance for the following reason: It is often assumed that the unstable states of the compounds formed during the precipitation, as, for example, CuAl_2 , or Al_3Mg_2 , are the cause of the intensified chemical activity. This, however, is not the case since there exists no bond in the Cu-Ag system and, nevertheless, heightened chemical activity and, therefore, a tendency toward intercrystalline corrosion exists. It may, therefore, be safe to say that this can be ascribed only to the high dispersiveness of the precipitations. A simple means to avoid it is the suitable choice of the precipitation temperature. A thorough elimination of the tendency to intercrystalline or stress corrosion may only be attained, however, if it is possible to remove the accelerating action of the grain boundaries on the precipitation and attain a pure microscopically homogeneous precipitation. In

that case no heat treatment could produce an intercrystalline corrosion sensitivity. To attain such control of the precipitation must be the object of further investigation.

Translation by S. Reiss,
National Advisory Committee
for Aeronautics.

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Figure 1.-
Stress
corrosion
cracks
in AZM,
delivery
condition
(magnification
100 times).

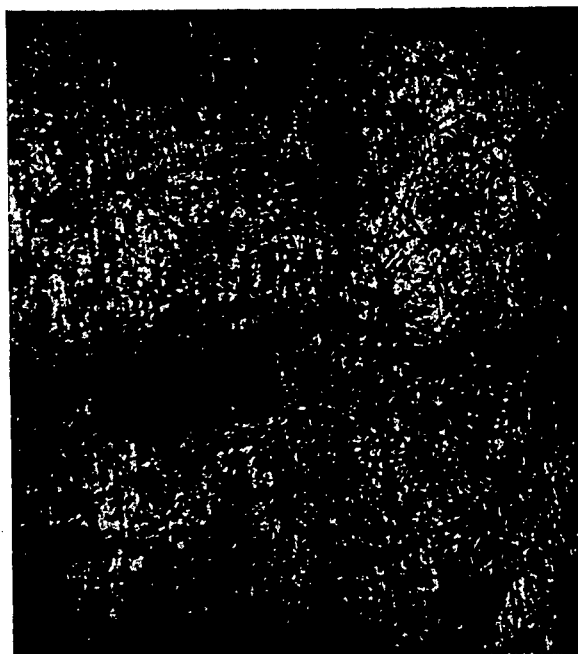


Figure 2.-
Stress
corrosion
crack
development
in the
texture
(AZM delivery
condition)
(magnification
300 times).

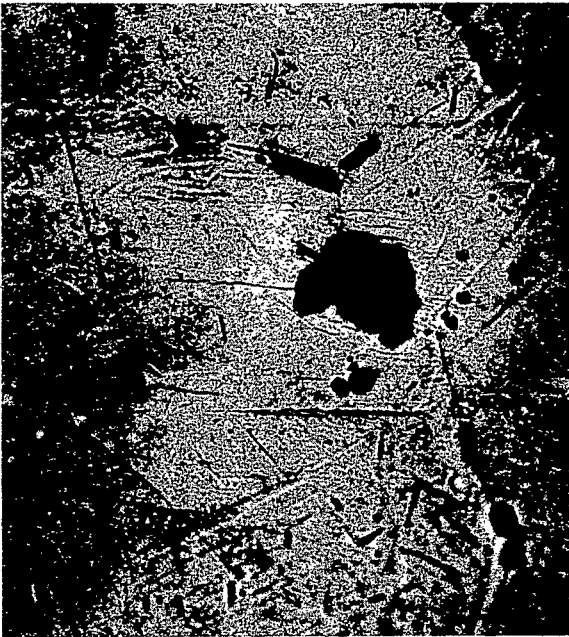


Figure 3.- (500x)

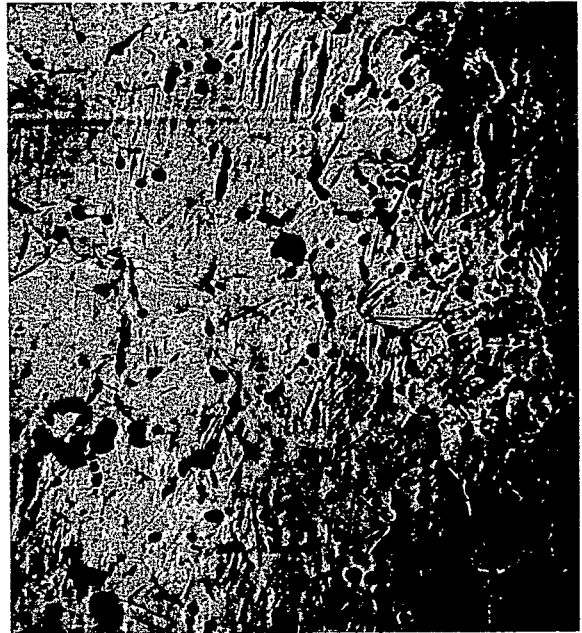


Figure 4.- (170x)

Figures 3 and 4.- Crack formation during plastic deformation in AZM (homogeneous state).



Figure 5.- (170x)



Figure 6.- (100x)

Figures 5 and 6.- Crack formation during plastic deformation in AZM and 3-hour stress corrosion in water.

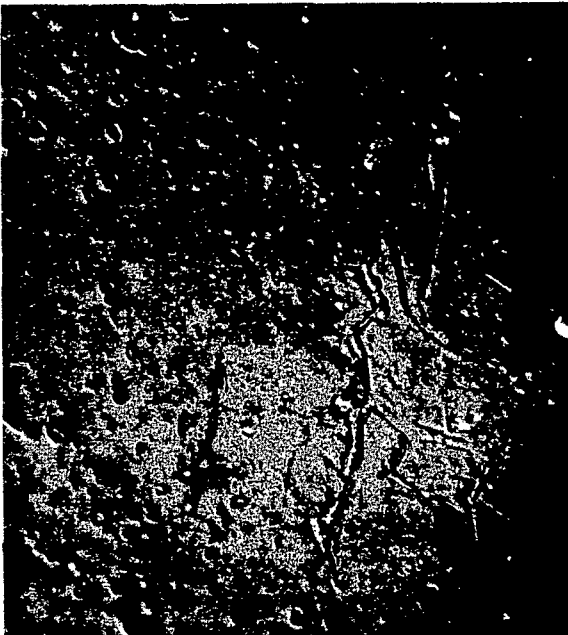


Figure 7.- (200x)

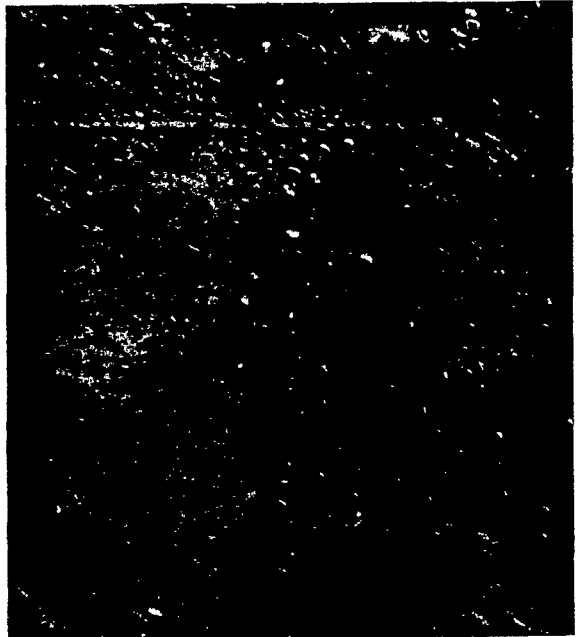


Figure 8.- (200x)

Figures 7 and 8.- Stress corrosion cracks in homogeneous AZM; development along the grain boundaries and through the grains but not along the slip planes.

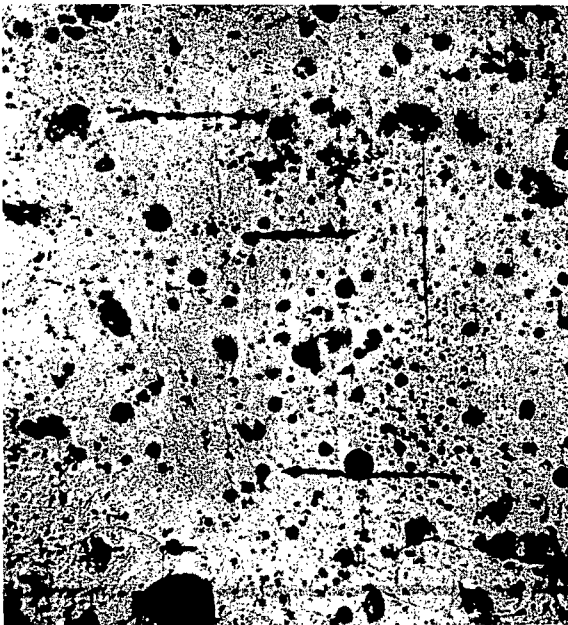


Figure 9.- Crack development in single-crystal AZM, direction of tension at right angles to the cracks (350x).

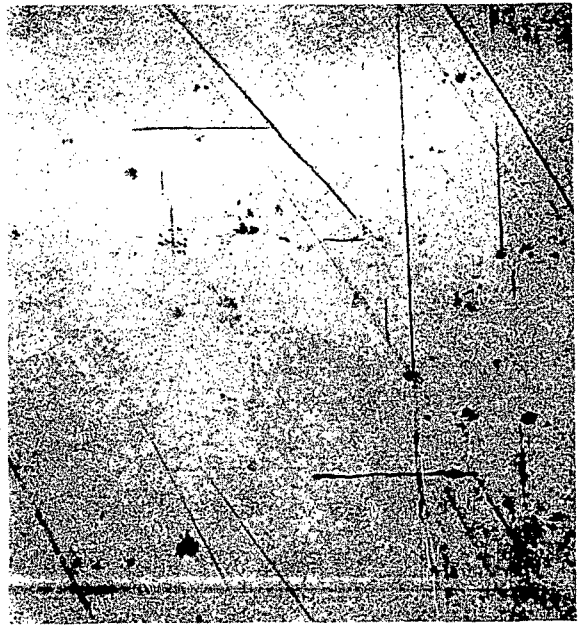


Figure 10.- The same part as figure 11 after grinding and polishing the surface (magnification 350x).

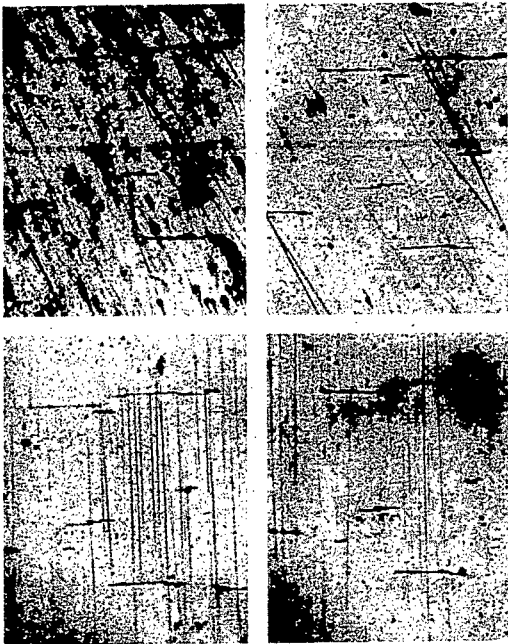


Figure 11.- Crack formation at various depths of the specimen; upper left- crack development at the corroded surface; lower right- after the strongest polishing.



Figure 12.- ↑
Undisturbed crack development through crystallite interspersed into the single crystal (500x).

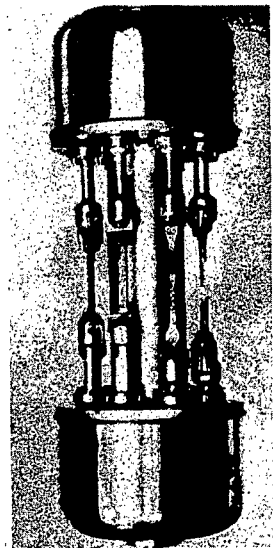


Figure 13.- Corrosion apparatus for 8 test specimens.



←
Figure 21.- Example of a microscopically homogeneous precipitation for an Mg-Al-Zn alloy (AZM) (magnification 250x)

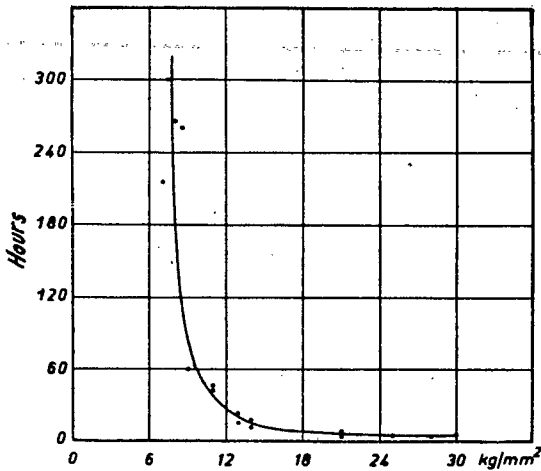


Figure 14.- Life of AZM sheet as a function of the load.

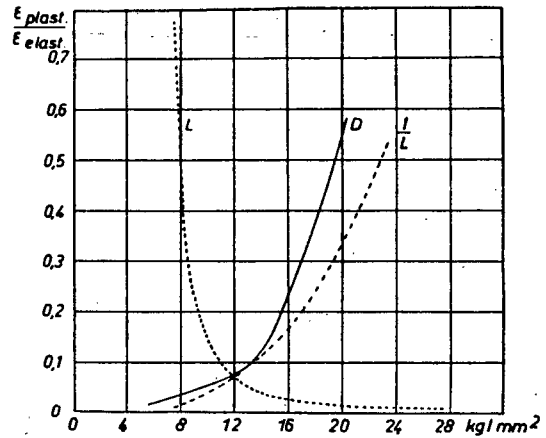


Figure 15.- Relation between plastic deformation D and tendency to stress corrosion, 1/L.

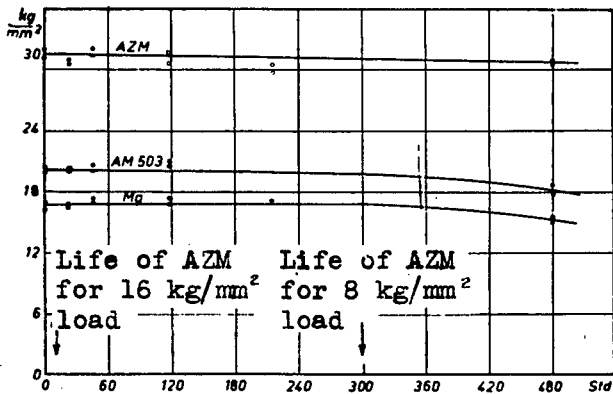


Figure 16.- Strength of unloaded specimens of Mg, AM503 and AZM as a function of the immersion time in water.

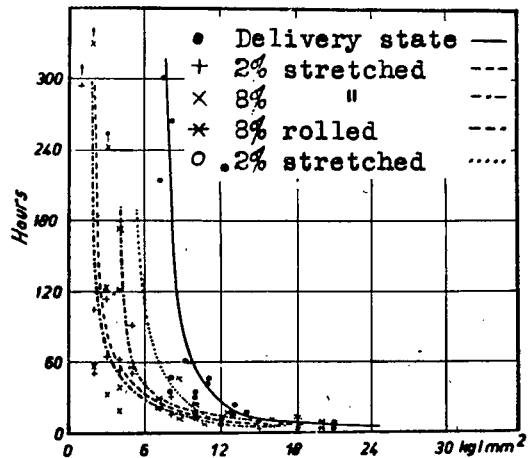


Figure 17.- Life of AZM specimens for various pretreatment as a function of the stress.

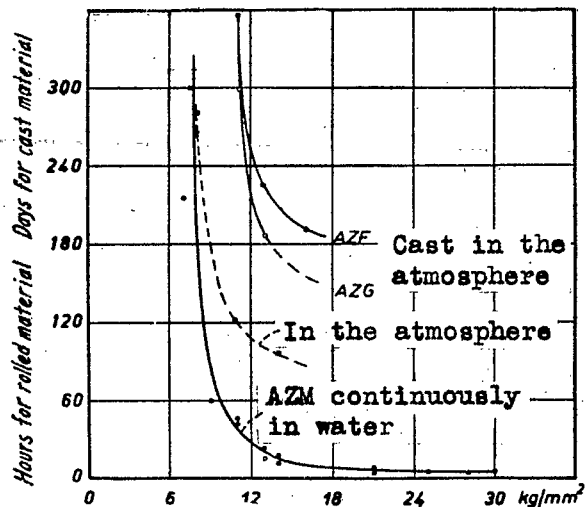


Figure 18.- Life of Mg cast and rolled alloys as a function of the load. Measurements of Siebel in the atmosphere and those of the author in water (lower curve).

Figure 19.- Dependence of stress corrosion sensitivity of hydronalium on Mg content and on the temperature, measurements of Althof.

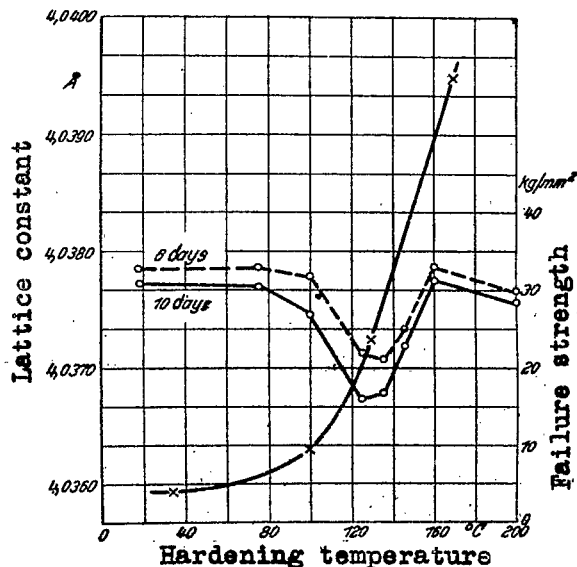
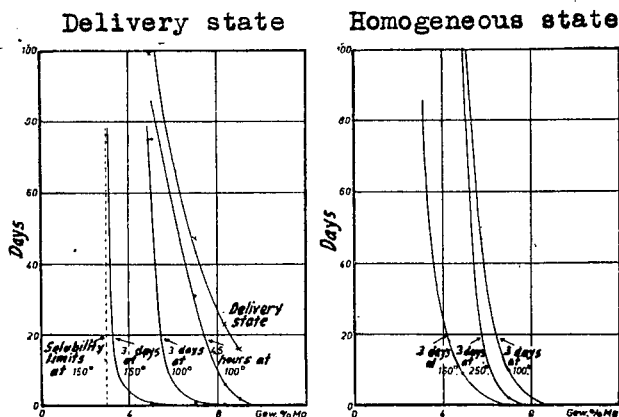


Figure 20.- Comparison of the change in the lattice constant with the resistance to corrosion as a function of the temperature for duralumin, according to Glocker and Giesen and according to Mann.

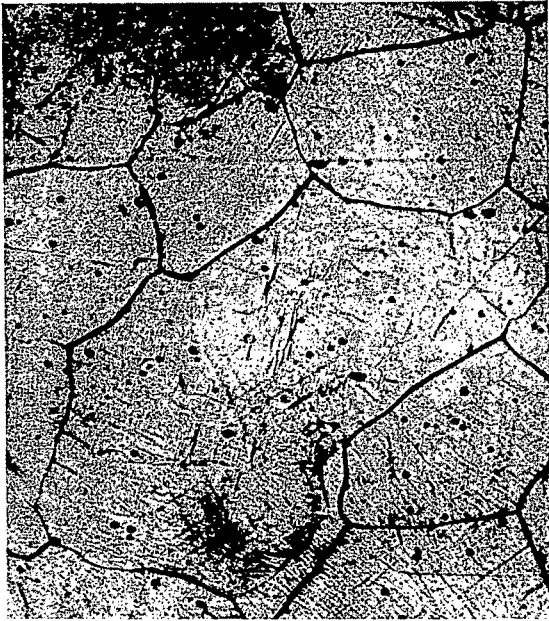


Figure 22.

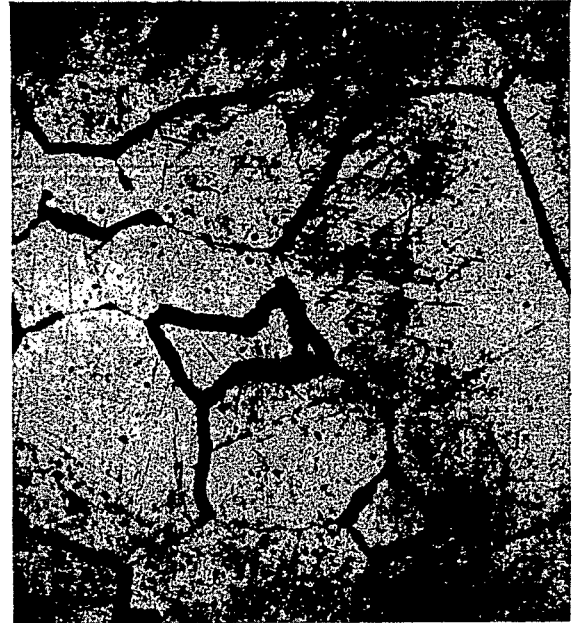


Figure 23.

Figures 22 to 24.- Example of a microscopically inhomogeneous precipitation after various time intervals, Ni-Be alloy (magnification 250x).



↑
Figure 24.

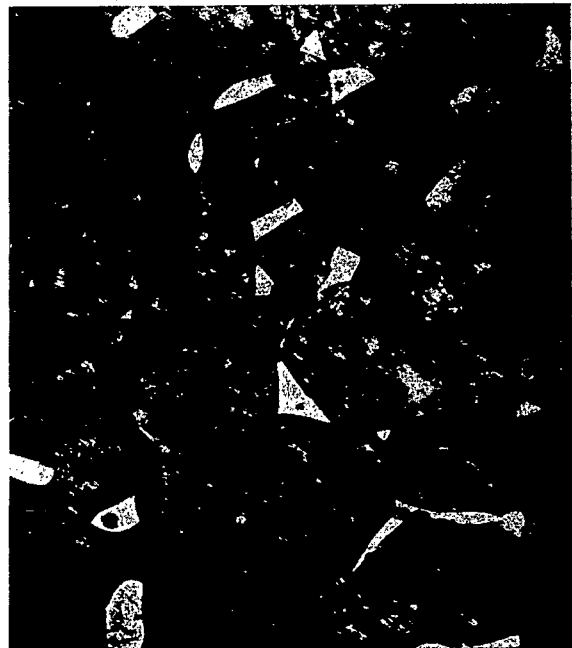


Figure 25.- Microscopically inhomogeneous precipitation for a Cu-Ag alloy: white- undissolved silver, grey- homogeneous mixture crystal, black- highly dispersive precipitated silver (positive film).

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